An appraisal of the relationship of delta smelt population dynamics and the position of the low-salinity zone in the San Francisco estuary – why the Delta Smelt Biological Opinion is not based on the "best available science"

The U.S. Fish and Wildlife Service and National Marine Fisheries Service are instructed by Congress to use the "best available scientific and commercial data" in implementation of the federal Endangered Species Act (ESA). The agencies reference that directive as the basis for informing their determinations in consultations under section 7 and in habitat conservation plans under section 10(a) of the Act. They require themselves to carry out an "effects analysis" as the means of meeting the best available science standard in support of their conservation actions (Murphy and Weiland 2011). It could therefore be expected that the analyses and findings in the 2008 Delta Smelt Biological Opinion (*Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP)*) regarding delta smelt population dynamics and the extent and quality of its habitat in the estuary in the autumn would meet the agencies' best available science criterion.

Such is not the case. The available data do not support the contention that an association exists between the location of the so-called X2 isohaline in the Sacramento-San Joaquin Delta and the population dynamics of delta smelt. And, a putative deterministic relationship between the location and extent of the low-salinity zone and the extent of suitable habitat for the delta smelt has not been substantiated. Importantly, the delta smelt biological opinion, released nearly three and a half years ago, has been remanded in federal court and a Section 7 re-consultation process has been initiated. The court found, among other things, that the Fish and Wildlife Service had failed to "examine the relevant data and articulate a satisfactory explanation for its action [its management prescription] including a rational connection between the facts found and the choice made" (Wanger 2011). In other words, the court found that the Service's recent delta smelt biological opinion was not based on the best available science.

The flows-management prescription that makes up the contested fall X2 management action is premised on an incorrect definition of delta smelt habitat and an inappropriate interpretation of actual habitat in the context of resource management. Referencing the Feyrer et al. studies, the Service contends in the delta smelt biological opinion that the position of X2 in the estuary in the autumn (1) accurately defines the habitat space that is occupied by delta smelt; (2) therefore, can serve as a "surrogate indicator" for the extent of delta smelt habitat; which (3) in its two-dimensional extent, measures habitat quality and the aerial extent of habitat for the species; and (4) it is a reliable predictor of delta smelt population dynamics. However, none of these assertions is supported by available data, therefore, the Service's basic premise has no empirical support.

The lack of any defensible ecological connection between the location of X2 in the estuary and the extent and quality of delta smelt habitat, and, in turn, any connection of these to the distribution and abundance of delta smelt has been called out in a report on the biological opinion by a blue-ribbon committee from the National Research Council. The NRC committee found that the “weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this [fall X2] action difficult to understand. In addition, although the position of X2 is correlated with the distribution of salinity and turbidity regimes (Feyrer et al. 2007), the relationship of that distribution and smelt abundance indices is unclear” (NRC 2012). In other words, a fundamental misunderstanding of the multi-dimensional complexity of habitat and misrepresentation of it as “abiotic habitat” – that is, as one or just a few physical variables – led to the conservation prescription in the biological opinion that the federal court late last year found unlikely to contribute to the recovery of delta smelt. The NRC committee further stated that the biological opinion is analytically inadequate, noting that the document’s “derivation of the details of this [fall X2] action lacks rigor. The [prescribed management] action is based on a series of linked statistical analyses (e.g., the relationship of presence/absence data to environmental variables, the relationship of environmental variables to habitat, the relationship of habitat to X2, the relationship of X2 to smelt abundance). Each step of this logical train of relationships is uncertain. The relationships are correlative with substantial variance left unexplained at each step, yet the analyses do not carry the uncertainty at each step to the next step.”

Following both the release of the delta smelt biological opinion and the NRC committee review of it, two pairs of multivariate modeling exercises investigated the potential causes of recent declines of delta smelt. All, like the Feyrer et al. studies, used delta smelt data from the Fall Midwater Trawl. In contrast to the Feyrer et al. studies, each considered a breadth of both physical and biotic attributes of the estuary. None found evidence that the location of X2 in the autumn was a substantive determinant of the decline of delta smelt or a contributor to its population dynamics. Thomson et al. (2010) used change-point analysis to investigate step changes in nearly two dozen candidate environmental factors, including the mean location of X2 in the estuary in the fall, which they surmised might have corresponded with the dramatic drop in delta smelt numbers that was sustained for much of the past decade. No signal of effects on delta smelt from the location of X2 in the estuary was identified. MacNally et al. (2010) used multivariate autoregressive modeling to evaluate 54 fish-environmental factor relationships, including the factors considered by Thomson et al., and found generally weak relationships, but enhanced signals from food availability and the position of the low-salinity zone in the spring. Maunder and Deriso (2011) used a multistage life-cycle model that varied levels of presumptive density dependence to consider environmental factors acting on delta smelt abundance and found a substantive deterministic relationship to be the availability of the fish’s food resources. The location of X2 in the autumn was not found to be a predictor of delta smelt abundance. The environmental data in that study were shared in a multivariate regression analysis by Miller et al. (2012), who asserted that their specification of environmental variables was spatially and temporally rectified to better reflect within-Delta patterns of environmental variation. They found food availability to be a major signal and predation and entrainment to be minor signals, with overarching effects from density dependence. Like Thomson et al., none of the latter three studies found evidence of a relationship between the location of X2 in the estuary in the autumn and delta smelt abundance.

There is no evidence that can be drawn from studies of environmental stressors to support the link made in the biological opinion between the location of X2 in the estuary in the autumn and trends in the fish's population numbers.

Because the location of the low-salinity zone in the estuary has only a weak spatial relationship with the extent and quality of delta smelt habitat (NRC 2012), and because there is no established connection between the location of the low-salinity zone in the estuary and the abundance of delta smelt (see Thomson et al. 2010, MacNally et al. 2010, Maunder and Deriso 2011, Miller et al. 2012), the central premise of the biological opinion's management prescriptions is unsupported. Therefore, the two critical assertions by the agency – that the location of the low-salinity zone in the estuary is linked to delta smelt population size (or performance or productivity) and that the extent of the low-salinity zone functionally represents the extent of habitat for delta smelt – deserve closer examination.

The data and analyses upon which management prescriptions in the biological opinion were largely based were drawn from Feyrer et al. (2007) and a then in-manuscript article, subsequently published as Feyrer et al. (2011). Feyrer et al. (2007) investigated patterns of delta smelt distribution across gradients of three physical environmental factors that vary in the estuary – water temperature, Secchi depth (turbidity), and conductivity (salinity). Using time-series population data for delta smelt derived from annual Fall Midwater Trawl and environmental data from the fish survey stations, the study matched the presence/absence of delta smelt with three abiotic characteristics to infer the preferences of the fish for conditions across the ranges of those three variables. Feyrer et al. (2007) found that salinity and turbidity explained 25% of the variance in delta smelt presence/absence across the estuary in the autumn. The article stated that "declines in habitat suitability were associated with anthropogenic modifications to the ecosystem" and noted that the results presented were "consistent with existing evidence of a long-term decline in carrying capacity in delta smelt," but offered little data or analyses to support those observations.

In the companion paper, Feyrer et al. (2011) drew from the previous work in developing a "habitat index," that "accounted for both the quantity and quality of abiotic habitat," and used it "to model the index as a function of estuarine outflow." The model used "general additive modeling to identify habitat suitability based on combinations of water temperature, clarity, and salinity from surveys conducted during fall," applying it "using outflow predictions under future development and climate change scenarios." The habitat index is the basis for the assertion in the biological opinion that prescribing locations of the low-salinity zone in the estuary in the fall can be used to benefit delta smelt. By reducing water exports from the estuary and/or increasing upstream reservoir releases, Feyrer et al. (2011) asserts that the areal extent of the low-salinity zone is increased, therefore, the extent of habitat for delta smelt is increased, which will lead to subsequently greater delta smelt performance.

The Feyrer et al. studies broke with previous work that showed no deterministic relationship between salinity and delta smelt population dynamics in other seasons (see Jassby et al. 1995, Kimmerer 2002, Kimmerer et al. 2009). Those studies directly and indirectly contributed to the reasoning and logic chain that led to specific target locations for X2 in the estuary in the autumn under different water-year conditions. A recent document, *Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability,* which is intended to guide implementation of studies aimed at determining if the biological opinion's autumn X2 prescriptions result in population benefits to delta smelt, explains the link between the Feyrer et al. studies and the determination that specific locations for the low-salinity zone are necessary to conserve the delta smelt with the statement: "Analysis of historical monitoring data by Feyrer et al. (2007) revealed that the abiotic habitat of delta smelt can be defined as a specific envelope of salinity and turbidity that changes over the course of the species' life cycle." But, that interpretation of findings from the published literature did not critically consider the shortcomings in the design of the studies and analyses found in the Feyrer et al. papers. Fundamental flaws in quantitatively linking the location of the low-salinity zone in the estuary to inferred effects on the extent and quality of delta smelt habitat that were introduced in the two papers were propagated in the biological opinion.

A number of conceptual missteps in the logic sequence connecting the low-salinity zone to delta smelt habitat (and then to delta smelt performance), as well as multiple analytical errors combine to compromise the ecological conclusions drawn in the biological opinion and applied to its management directives. First, and of primary concern, is that Feyrer et al.'s (2007) investigation of environmental correlates of delta smelt occupancy in the estuary was limited to just three physical variables; it ignored other physical variables that appear in the agency's own conceptual models linking delta smelt population responses to environmental attributes, and disregarded biotic variables such as food availability and the presence of predators altogether. Accordingly, the three variables combined could explain just a quarter of the variance in patterns of delta smelt presence/absence in the estuary. Because of the modeling approach used, it is unclear what portion of the variance is actually due to turbidity rather than salinity. In any case, the parsimonious conclusion from the Feyrer et al. (2007) study should be that the better predictor of delta smelt presence/absence across the estuary would undoubtedly be found among variables that were not investigated, which combine to explain the other 75% of the variance in the fish's distribution.

Second, the characterization of delta smelt as preferentially inhabiting just a portion of the estuary's low-salinity zone is drawn at least in part from a mischaracterization of that distributional relationship as presented in Feyrer et al.

(2007) and perpetuated in Feyrer et al. (2011). Feyrer et al. (2007) and the biological opinion fail to correct for the fact that many more FMWT survey stations in the Delta are located in areas that typically experience a circumscribed range of low-salinity conditions. Actually correcting for the indisputable bias in sampling in the FMWT survey frame produces a nearly even distribution for delta smelt across a wide and continuous range of salinity conditions (Merz et al. 2011). Exacerbating that sampling bias, Feyrer et al.'s (2007) study did not consider the full geographic extent of available survey stations; it used just 75 of 100 FMWT sampling locations, ignoring, for example, sampling in Cache Slough region and the Sacramento Deep Water Ship Channel that have been shown in recent years to serve as important habitat for delta smelt despite being completely independent of X2 location. The Cache Slough region in the northeast estuary, where an apparent demographic unit resides year-round, experiences near-freshwater conditions. This demographic unit has contributed as much as a third of the total numbers of delta smelt in autumn samples in recent years. That sub-sampling design flaw in Feyrer et al.'s (2007, 2011) study assures that inter-annual patterns of delta smelt occupancy in the estuary are incorrectly biased toward downstream areas.

Third, Feyrer et al. (2011) developed a "habitat index" that incorporated data generated by the above sampling shortcomings, which was used to make predictions regarding the availability of habitat under different water flows scenarios. The "habitat index" improperly links several statistical models without accounting for the attending uncertainty in each, with the accompanying uncertainties multiplied with the addition of each model link (NRC 2012). More compromising yet, the ostensible relationship that Feyrer et al. (2011) identifies between the "habitat index" and delta smelt abundance suffers from induced correlation, with delta smelt abundance data (derived from FMWT survey returns) appearing on both axes of a graph that is presented to illustrate the relationship (Figure 2c, Feyrer et al. 2011). Accordingly, the "habitat index" that is essential to the management prescriptions in the biological opinion is statistically invalid.

Notwithstanding the misrepresentation of a relationship between the location of X2 in the estuary and the numbers of and trends in delta smelt, the fundamental premise for the management directive in the biological opinion is that delta smelt habitat can be characterized for purposes of conservation planning as an "area of suitable abiotic habitat." But, habitat for delta smelt surely is not solely the surface area or volume of water that exhibits a range of conditions for several physical variables. The habitat of a species includes the geographic areas it occupies, all of the resources it uses, and the conditional states of those resources. They include both physical and biological resources, which combined provides the environmental elements necessary for the survival, persistence, and recovery of an organism. Habitat quality invariably varies across its extent. For delta smelt, variation in habitat quality can occur with variability in availability of food, shelter from predators, substrates for spawning, and a large number of physical variables, including salinity, turbidity, and temperature. The best habitat for delta smelt is designated so by its comparative capacity to support and sustain the fish; and, that habitat can be found high (upstream) in the estuary at, in, and near freshwater conditions, and low (downstream) in the estuary (in and adjacent to Suisun Bay), where salinity conditions can be the highest in the Delta. Variability in salinity, measured as the location of X2 in the estuary, has not been shown to affect the survival of delta smelt or trends in its population numbers, nor the abundance or condition of any of the biotic resources that contribute to its habitat. The location of X2 in the estuary in the autumn does not predict or determine the location of other resources that contribute to delta smelt habitat. The extent of the low-salinity zone largely overlaps with the distribution of other essential physical resources and key biotic resources that are necessary to support delta smelt, but the extent of the low-salinity zone in the autumn does not define the extent of habitat for delta smelt.

A standing description of delta smelt habitat has been offered by Hamilton and Murphy (in review). The extent of habitat for delta smelt is appropriately described as the multi-dimensional space that is seasonally occupied by delta smelt including "areas in the northern and central estuary that are characterized by complex bathymetry, with deep channels close to shallows and shorelines, with little submerged vegetation, but immediately bounded by extensive tidal or freshwater marshlands. Such situations appear to contribute to local production of diatom-rich phytoplankton communities that support calanoid copepods, in particular *Eurytemora affinis*, *Pseudodioptomus forbesi*, and some cyclopoid zooplankton, which are frequent in the diets of delta smelt (Schemel et al. 2004). The fish demonstrates affinities for waters that experience salinity in the range of 200-8000 EC, a water transparency less than 50 cm, and temperatures below 22 degrees Celsius, with preferred conditions varying somewhat with life stage. Before spawning, delta smelt initiate a diffuse landward dispersal to fresher-water circumstances (Bennett 2005) and, while little is known about the microhabitat conditions required for successful spawning, preferred substrates may include clean cobble or sandy surfaces to which eggs are adhered. Delta smelt frequently are found in open water situations, but less so during spawning. Where pre-spawning delta smelt must disperse greater distances to spawning areas, intervening areas of the estuary, including some areas with conditions less suitable for delta smelt, are included as habitat." The dynamic spaces that exhibit those characteristics surely have identifiable locations and are measurable in extent, but no focused effort to do so has been made by scientists or planners working in the Delta.

While Feyrer et al. (2007) noted that "other factors," including several of those noted above contribute to delta smelt habitat, and the delta smelt biological opinion recognized that multiple resources and other environmental factors contribute to the survival and recovery of delta smelt, the biological opinion nonetheless contends that the location of X2 in the estuary in the fall can be used as a "surrogate" for delta smelt habitat for purposes of water management planning (BiOp pp. 234, 369, 373). Because the extent of open waters is greater in western, downstream areas of the estuary, when the X2 is located in those downstream areas, the low-salinity zone is more expansive; hence, according to the biological opinion (drawing guidance from Feyrer et al. 2011) more habitat is available to support delta smelt. But, best available scientific information and ecological theory shows that the assertion that the location of X2 in the estuary in the autumn is an appropriate indicator of the extent of delta smelt habitat is not supported.

An ecological indicator or management surrogate is an environmental attribute that responds to relevant ecological conditions in a manner similar to a target species or its habitat, where direct data for the species or its habitat are too difficult, inconvenient, or expensive to gather (see Landres et al. 1988, Caro 2010). Default to inference from indicators or surrogates in natural resources management has intuitive appeal, particularly in the case of the delta smelt, given its elusive behavior and residence in turbid waters that obscure its interactions with its environment, making it especially difficult to observe or census. It is best-scientific practice for wildlife or fisheries managers to determine whether the presence of an indicator or surrogate accurately predicts the presence of the target before employing such planning proxies in management practice (Caro et al. 2005, Wenger 2008). The federal land management and wildlife agencies have been frequently criticized by scientists for uncritical identification and acceptance of environmental indicators based on surmise and assertion (Landres et al. 1988, Noon et al. 2005, Cushman et al. 2010).

There are three criteria that an ecological indicator must fulfill to establish its validity, and ultimately its utility, for use as a surrogate representing habitat for a species in the context of conservation planning –

1) the indicator must spatially and temporally occur over much of the geographic range of the target species and the distribution of its habitat;

2) there must be an ecological mechanism by which the indicator controls or affects the distribution or abundance of the species, or extent or condition of its habitat;

3) the status of the indicator must be anticipatory of changes in the status of the species or its habitat; that is, a measurable change in the indicator will predict changes in population numbers or habitat conditions that can be averted by management action.

(consistent with Dale and Beyeler 2001, Hunsaker et al. 1990, Niemi and McDonald 2004.)

The use of the location of X2 in the estuary in the fall as an indicator of the extent of habitat for delta smelt and as a surrogate measure for water management planning directly fails each criterion above – and, very clearly, the essential first one. An effective surrogate measure for delta smelt habitat must exhibit a high degree of spatial and temporal overlap with the distribution of delta smelt. Maps are available that document the co-occurrence between delta smelt and the geographically dynamic low-salinity zone which show that relationship is not especially tight (see Merz et al. 2011, Hamilton and Murphy in review). Delta smelt can be found at salinities substantially greater than X10, as much as five times the X2 concentration and well outside the X0.5 to X3.5 range often used to describe the low-salinity zone (see Heib and Fleming 1999, Moyle et al. 2010). Moreover, delta smelt are found in substantial numbers in near-freshwater portions of the estuary in upstream areas unaffected by the location of the X2 isohaline. Furthermore, large portions of the Delta that experience X2 and near-X2 conditions are not occupied by delta smelt in the fall and have not been occupied during most of the past decade. Those areas appear not to be suitable for delta smelt, either because of inadequate turbidity conditions or seasonally excessive temperatures (Hamilton and Murphy in review); hence, despite acceptable salinities, those extensive areas do not serve as habitat for delta smelt. Accordingly, on the one hand, the low-salinity zone, as described in the biological opinion, does not include significant areas of delta smelt habitat and, on the other hand, much of the low-salinity zone frequently does not support delta smelt. It therefore cannot be said that the low-salinity zone serves as "core habitat" area for the species, as suggested by Feyrer et al. (2007, 2011). Because the location and extent of the low-salinity zone in the estuary in the autumn only weakly overlaps the distribution of delta smelt, it is inappropriate to use it as a surrogate measure for purposes of resource management that requires designation of the location and extent of habitat for delta smelt.

In conclusion, the biological opinion's autumn X2 management prescription is based at best, on weak statistical analyses without consideration of significant uncertainty and, at worst, on a flawed definition of "habitat" and misuse of three abiotic water quality characteristics as a surrogate for "suitable habitat," all while using only a subset of the actual known habitat area utilized by delta smelt. Several recent peer-reviewed and published articles, which specifically examined, among other factors, the importance of the location of X2 in the autumn and subsequent delta smelt performance, were unable to identify such a relationship.

Hamilton and Murphy (in review) provides life stage-specific affinity analyses and maps indicating delta smelt preferences for numerous abiotic and biotic habitat characteristics, such as salinity, temperature, food resources, and bathymetry. Sommer et al. (submitted) attempts to describe delta smelt preferences for habitat characteristics using historical survey data. Approaches such as these offer greater insight into the true habitat needs of delta smelt and where such "suitable" habitat is located in the estuary.

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